

CS 603: Programming Language Organization

Lecture 10

Spring 2004

Department of Computer Science

University of Alabama

Joel Jones

Outline

- Questions
- S-expressions
- μ -Scheme (cont.)
- Reading for next time

S-expressions

- s-expression – a *symbol*, a *number*, or a *list* (S_1, \dots, S_n) of zero or more S-expressions
- nil list – list of zero elements $()$

Operations on S-Expressions:

- Review
 - car: first element of list or '()
 - cdr: everything in list except first element
 - cons: if $S = (S_1, \dots, S_n)$, then $(\text{cons } S' S)$ is $(S' S_1, \dots, S_n)$
- Predicates
 - =: returns #t if equal, #f otherwise, for non-lists and empty lists
 - number?, symbol?, list?, null?: #t if argument of type, #f otherwise
 - <, >: #t if both numbers and condition holds, #f otherwise
- Math
 - +, -, *, /: like impcore

Syntax

(changes from impcore)

- `value ::= integer | quoted-const`
- `value-op ::= + | - | * | / | = | < | > | cons | car | cdr | number? | symbol? | list? | null? | print`
- `quoted-const ::= 'S-expression`
- `S-expression ::= integer | symbol | (S-expression*)`
- `symbol ::= name`

Example of a list using function

- ```
(define length (lambda (l)
 (if (null? l)
 0
 (+ 1 (length (cdr l))))))
```

# Let's play at the board again (No Books!)

- `(list1 x)` - list of one element, x
- `(list2 x y)` - list of two elements, x and y
- `(list3 x y z)` - list of three elements, x, y, and z
- `(atom? x)` - #t if null, number, or symbol, #f otherwise
- `(equal l1 l2)` - #t if two equal atoms or equal lists, #f otherwise. Two lists are equal if same length and corresponding elements are equal.

# Larger LISP Example

- Calculate prime numbers less than  $n$  using Sieve of Eratosthenes.



# Let's Play at the Board

## (but your books can't play)

- Insertion sort—given a list of  $n$  elements, sort the last  $n-1$  recursively, then insert the first in its proper position.
- `(define insert (x l) ...`
- `(define insertion-sort (l) ...`

# Association Lists

- association list(a-list)—a list of the form  $((k_1 a_1), \dots, (k_m a_m))$ , where the  $k_i$  are symbols (called *keys*) and the  $a_i$  are *attributes*.

- retrieve data:

```
(define assoc (x alist)
 (if (null? alist) '()
 (if (= x (caar alist)) (cadar alist)
 (assoc x (cdr alist)))))
```

# Association Lists (cont.)

- add data

```
(define mkassoc (x y alist)
 (if (null? alist)
 (list1 (list2 x y))
 (if (= x (caar alist)
 (cons (list2 x y) (cdr alist))
 (cons (car alist) (mkassoc x y (cdr
alist))))))
```

# Let's play at the board again (No Books!)

- Property lists—a list where attribute is an attribute list
- Examples
  - `(set fruits '((apple ((texture crunch)))  
                  (banana ((color yellow))))))`
  - `(getprop 'apple 'texture fruits)`  
crunchy
- Write `(getprop x p plist)`, where `x` is the individual, `p` is the property and `plist` is the property list

# Let's play at the board again (No Books!)

- `(putprop x p y plist)` give individual x value y for property p in plist
  - `(set fruits (putprop 'apple 'color 'red fruits))`  
`->((apple ((texture crunchy)(color red)))(banana ((color yellow))))`

# $\mu$ -Scheme

- Closures

- Pair of lambda (function value) and environment
  - «(lambda (y) ...), {x |→ l}»
- Environment maps name to mutable location

```
->(val counter-from
 (lambda (n)
 (lambda () (set n (+ n 1)))))
->(val ten (counter-from 10))
<procedure>
->(ten)
11
->(ten)
12
```

# μ-Scheme (cont.)

- Closures

Pair Up:

- Write a function (make-withdraw) that models a bank account balance, where only withdrawals are allowed

```
->(val make-withdraw (lambda (balance) ...))
```

```
->(val W1 (make-withdraw 100))
```

```
->(W1 10)
```

90

# Simple higher-order functions

- Composition

- (define o (f g) (lambda (x) (f (g x))))
- (define even? (n) (= 0 (mod n 2)))
- (val odd? (o not even?))

Pair Up:

- Write a function (to8th) using composition with square and ? that raises the input to the 8th power

```
-> (define square(x) (* x x))
```

```
square
```

```
-> (val to8th ...)
```

```
<procedure>
```

```
-> (to8th 2)
```

```
256
```



# Simple higher-order functions (cont.)

- Currying
  - Taking an  $n$ -argument function and turning it into a 1-argument function returning a function expecting  $n-1$  arguments (also curried!)
  - Currying binary functions
    - (define curry (f) (lambda (x) (lambda (y) (f x y))))
    - (define uncurry (f) (lambda (x y) ((f x) y)))

# Simple higher-order functions (cont.)

- Currying

```
->(val zero? ((curry =) 0))
->(zero? 0)
#t
->(val add1 ((curry +) 1))
->(add1 4)
5
->(val new+ (uncurry (curry +)))
->(new+ 1 4)
5
```

# Higher-order functions on lists

- Filter –

```
(define filter (p? l)
 (if (null? l) '()
 (if (p? (car l))
 (cons (car l) (filter p? (cdr l)))
 (filter p? (cdr l)))))
```

- Exists? –

```
(define exists? (p? l)
 (if (null? l) #f
 (if (p? (car l))
 #t
 (exists? p? (cdr l)))))
```

# Higher-order functions on lists (cont.)

- All? –

```
(define all? (p? l)
 (if (null? l) #t
 (if (p? (car l))
 (exists? p? (cdr l))
 #f)))
```

- Map –

```
(define map (f l)
 (if (null? l) '()
 (cons (f (car l)) (map f (cdr l)))))
```

Pair Up:

- How are the arguments of `filter`, `exists?`, and `all?` different from those of `map`?

# Higher-order functions on lists (cont.)

---

- Foldr
- Foldl

# Higher-order functions for polymorphism

- Implementing sets
  - Constructing mono-morphic sets requires definition of equality — simple if primitive elements

```
->(val emptyset '())
->(define member? (x s) (exists? ((curry equal? x) s))
->(define add-element (x s) (if (member? X s) s (cons x s)))
->(define union (s1 s2) (foldl add-element s1 s2))
->(define set-from-list (l) (foldl add-element '() l))
```

- Problem is equality for complex types

# Higher-order functions for polymorphism (cont.)

Pair Up:

- Implement a data type for sets which uses the usual list representation. Therefore, all you have to do is implement `=set?`

```
->(=set? '(a b c) '(c b a))
```

```
#t
```

- Implement sets of sets, where the set functions are passed an `eqfun` for comparing sets.

```
->(define member? (x s eqfun) ...)
```

```
->(define add-element (x s eqfun) ...)
```

# Higher-order functions for polymorphism (cont.)

- How to construct?
  - Add parameter to *every* function
  - Make part of “object” (set in previous example)
  - Make list of functions (like C++ templates)



# Reading & Questions for Next Class

- Chapter 3.11–3.14